



Budburst Protocol

Students will select trees at a Land Cover Sample Site or Phenology Site and observe budburst.

Green-Up Protocol

Students will monitor the budburst and growth of leaves of selected trees, shrubs or grasses.

Green-Down Protocol

Students will use a GLOBE Plant Color Guide to monitor the change in color of selected leaves of trees, shrubs or grasses.

Ruby-throated Hummingbird (RTHU) Protocol**

Students will observe the arrival and departure of Ruby-throated Hummingbirds, monitor hummingbird visits to flowers and feeders, and observe nesting behavior.

Lilac Phenology Protocol*

Students record the five pheno phases of either common or clonal lilac plants.

Phenological Gardens Protocol**

Students plant a garden and observe the flowering and leaf development stages of specified plants throughout the year.

Seaweed Reproduction Phenology Protocol*

Students collect specified seaweed species and observe the reproductive phenological phases of the seaweed.

Arctic Bird Migration Monitoring Protocol*

Over the year, students observe when specified migratory bird species first arrive and count their numbers until few or none of them remain.

* See the full e-guide version of the Teacher's Guide available on the GLOBE Web site and CD-ROM.

** Separate print version available on request to schools in the areas where the protocol may be conducted. The protocol and related material are also available in the e-guide version of the *Teacher's Guide* available on the GLOBE Web site and CD-ROM.

Introduction



Why Study Phenology?

Each year, as conditions for plant growth improve, a wave of green spreads over the land surface (green-up) and then retreats as conditions for plant growth decline (green-down). These waves are important because they are directly related to global carbon fixation and the amount of carbon dioxide (CO₂) in the atmosphere. The period between green-up and green-down or *senescence* is known as the *growing season*, and changes in the length of the growing season may be an indication of global climate change. For example, some scientists recently found that the growing season has increased in northern latitudes by eight days since the early 1980s. However, their conclusion is controversial because it was based only on satellite data. On-the-ground observations of plant green-up and green-down are needed to validate these types of satellite estimates.

Why Take Phenology Measurements

Estimates based on remote sensing data from satellites vary because of problems such as interference from small and large clouds, atmospheric haze, and other atmospheric properties that affect the greenness values that satellites detect. Other problems such as low sun angles at high latitudes, change of sun angle with seasons, poor viewing geometry, and aging of satellite detectors can affect scientist's estimates of greenness as well. GLOBE student observations are the only global network of ground-based plant phenology observations and will help scientists validate their estimates of global growing season changes that they derive using satellite data.

The Big Picture

Phenology is the study of living organisms' response to seasonal and climatic changes in their environment. Seasonal changes include variations in day length or duration of sunlight, precipitation, temperature and other life-controlling factors. The focus of this investigation is plant phenology during green-up and green-down. The plant growing season generally corresponds to the period between green-up and green-down. Green-up and green-down can be used to examine regional and global vegetation patterns, year-to-year trends, and vegetation responses to climate change.

Plant green-up is initiated when *dormancy* (a state of suspended growth and metabolism), is broken by environmental conditions such as longer hours of sunlight and higher temperatures in temperate regions, and rains and cooler temperatures in deserts and semi-arid areas. As plants begin green-up, leaf chlorophyll absorbs sunlight for photosynthesis. Photosynthesis fixes carbon dioxide from the atmosphere, using the carbon atoms to form plant tissue. To help in developing computer models of atmospheric carbon dioxide, scientists need accurate information about the timing and duration of global greenness (when photosynthesis is actively going on during daylight). This is especially important because the length of the plant growing season seems to have increased dramatically in some parts of the globe. Monitoring the length of the growing season is important for detecting climate change and for understanding the carbon cycle – one of the key biogeochemical cycles discussed in the introduction.

As plants photosynthesize, they also transpire water from the soil, through the roots and plant stems, and out the leaves into the atmosphere. This affects atmospheric temperature and humidity, and soil moisture. With green-down, plant transpiration of water decreases; plants reduce water loss when their water supply is

greatly limited during winters for deciduous plants and during dry spells for desert plants. Therefore, knowing the timing of green-up and green-down is important for understanding the global water cycle. Scientists also use greenness estimates from satellites to map wild fire danger. High greenness areas represent lower wildfire danger, while low greenness areas represent higher wildfire danger. Scientists studying migrations of animals such as caribou use greenness maps to help them understand animal population migration patterns.

As discussed in the *Land Cover/Biology Investigation*, healthy green plants reflect much more near-infrared sunlight than visible light. Remote sensing scientists use visible and near-infrared reflectance estimates from satellites to derive a greenness index. New and better satellite data are now available from the MODIS (Moderate Resolution Imaging Spectrometer) instrument on board NASA's Terra satellite launched in December 1999. This satellite is part of a coordinated international effort to use many satellites and instruments to study the global environment. However, scientists will need GLOBE student observations of plant phenology to help them validate estimates of greenness from around the world taken by these and other satellite systems.

Measurement Logistics

GLOBE supports three plant phenology protocols: Budburst, Green-up, and Green-down. The *Budburst* and *Green-up* Protocols are related but are designed for different situations. Green-up and Green-down have the same site requirements. The *Budburst Protocol* is more appropriate if one or more of following conditions is met.

1. Students cannot reach the buds on the trees to measure the lengths of the leaves with a ruler as is required for Green-up.
2. Your school will be on summer vacation before the full sequence of Green-up is complete. This can occur for schools located in very cold climates where spring growth begins late in the year. (If time permits, students could do the Green-down in the autumn when school is in session.)
3. The teacher does not want to commit to the added time required for Green-up. Green-up and Green-down allow for a more in-depth and quantitative analysis of plant phenology.

Protocol	Budburst	Green-Up	Green-Down
What procedures are performed?	Observe and report dates of green-up	Observe and report dates of green-up and leaf growth	Observe and report dates of green-down color changes
Where are procedures conducted?	Plant Phenology Study Site; Site close to Atmosphere and Soil Moisture and Temperature Study Sites is preferred		
When are procedures conducted?	Twice weekly, starting at least two weeks before estimated initial budburst, then daily until budburst is seen on three places on tree	Twice weekly, starting at least two weeks before estimated initial budburst until leaf length stops increasing	Twice weekly, starting two weeks before estimated initial green-down until leaf color change is complete or leaves fall off
What equipment is needed?	Data sheets, plant identification keys	Permanent marker, ruler with mm scale, compass, camera, Data Sheets, plant identification keys, calculator (optional)	Permanent marker, GLOBE Plant Color Guide, compass, camera, plant identification keys, Data Sheets



Educational Objectives

Students participating in the activities presented in this chapter should gain inquiry abilities and understanding of a number of concepts. These abilities include the use of a variety of specific instruments and techniques to take measurements and analyze the resulting data along with general approaches to inquiry. The *Scientific Inquiry Abilities* listed in the gray box are based on the assumption that the teacher has completed the protocol including the *Looking At The Data* section. If this section is not used, not all of the Inquiry Abilities will be covered. The *Science Concepts* included are outlined in the United States National Science Education Standards as recommended by the US National Research Council and include those for Earth and Space Science and Physical Science. The *Geography Concepts* are taken from the National Geography Standards prepared by the National Education Standards Project. Additional *Enrichment Concepts* specific to the hydrology measurements have been included as well. The gray box at the beginning of each protocol or learning activity gives the key concepts and scientific inquiry abilities covered. The following tables provide a summary indicating which concepts and abilities are covered in which protocols or learning activities.

National Science Education Standards: Phenology

National Science Education Standards	Protocols				
	Budburst	Green-up	Green-down	Humming-birds	Phenological Gardens
Earth And Space Sciences					
Changes in the Earth and Sky (K-4)					
Weather changes from day to day over the seasons.	■	■	■		■
Weather can be described by measurable quantities					■
Properties of Earth Materials (K-4)					
Soils have properties of color, texture and composition; they support the growth of many kinds of plants.					
Structure of the Earth System (5-8)					
Soil consists of weathered rocks and decomposed organic matter					
Water circulates through the biosphere, lithosphere, atmosphere and hydrosphere (water cycle)					
Energy in the Earth System (9-12)					
The sun is the major source of energy at Earth's surface	■	■	■		■
Life Sciences					
The Characteristics of Organisms (K-4)					
Organisms have basic needs.		■	■	■	■
Organisms can only survive in environments where their needs are met	■	■	■	■	
Earth has many different environments that support different combinations of organisms		■	■	■	
Organisms and their Environments (K-4)					
Organisms' functions relate to their environment		■	■	■	■
Organisms change the environment in which they live	■	■	■		
Life Cycles of Organisms (K-4)					
Plants and animals have life cycles	■	■	■	■	■
Plants closely resemble their parents					■
Regulation and Behavior (5-8)					
All organisms must be able to obtain and use resources while living in a—constantly changing environment				■	■
The Interdependence of Organisms (9-12)					
Organisms both cooperate and compete in ecosystems				■	
The population of an ecosystem is limited by its resources				■	
Matter, Energy, and Organization in Living Systems (9-12)					
Energy for life derives mainly from the sun	■	■	■		■
Living systems require a continuous input of energy to maintain their chemical and physical organizations	■	■	■		■
The Behavior of Organisms (9-12)					
The interaction of organisms in an ecosystem have evolved together over time				■	
Geography					
The World in Spatial Terms (K-12)					
Plants help to define the character and spatial distribution of ecosystems on the Earth's surface.					■

